

LA-UR -81-325

CONF - 810212 - - 2

TITLE: COMPACT TOROIDS GENERATED BY A MAGNETIZED
COAXIAL SOURCE IN THE CTX EXPERIMENT

MASTER

AUTHOR(S): A. R. Sherwood, I. Henins, H. W. Hoida, T. R. Jarboe,
K. F. McKenna, R. K. Linford, J. Marshall, D. A. Platts

SUBMITTED TO: U.S.-Japan Workshop on Compact Toroids
at Osaka, Japan, February 17-19, 1981

DISCLAIMER

This document contains information which is the property of the United States Government. It is loaned to you for your information and use only. It is not to be distributed outside your organization. It is not to be used for any purpose other than that for which it was loaned to you. It is to be returned to the United States Government upon request. It is to be destroyed when it is no longer needed. It is to be kept in a secure place. It is to be protected from loss, theft, and damage. It is to be handled in accordance with the rules and regulations of the United States Government. It is to be used in accordance with the terms and conditions of the loan agreement. It is to be returned to the United States Government upon request. It is to be destroyed when it is no longer needed. It is to be kept in a secure place. It is to be protected from loss, theft, and damage. It is to be handled in accordance with the rules and regulations of the United States Government. It is to be used in accordance with the terms and conditions of the loan agreement.

University of California

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos Scientific Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.



LOS ALAMOS SCIENTIFIC LABORATORY

Post Office Box 1663 Los Alamos, New Mexico 87545

An Affirmative Action/Equal Opportunity Employer

COMPACT TOROIDS GENERATED BY A MAGNETIZED COAXIAL SOURCE IN THE CTX EXPERIMENT

A. R. Sherwood, I. Henins, H. W. Hoida, T. R. Jarboe, R. K. Linford,

J. Marshall, K. F. McKenna, and D. A. Platts

Los Alamos National Laboratory

Los Alamos, New Mexico, USA.

AS12470

ABSTRACT

Compact toroids containing both toroidal and poloidal magnetic field (Spheromak-type) have been generated in CTX using a magnetized coaxial plasma gun. These CTs tear loose from the gun by magnetic field line reconnection, and they are trapped in flux conservers having various geometries. In a straight cylindrical flux conserver the CTs are observed to be unstable to a gross tilting mode. Stability to the tilting mode has been demonstrated in flux conservers having an oblate trapping region; however, the geometry of the entrance region leading to the trapping volume can also have important effects. Lifetimes of about 150 μ s for the CTs are typically observed. Interferometric measurements give a value of about $2 \times 10^{14} \text{ cm}^{-3}$ for the initial plasma density. The plasma temperature measured at a single spot near the minor magnetic axis decreases to around 10 eV by the time the magnetic reconnection is complete. Spectrographic measurements and pressure probe results are in agreement with this temperature. A sniper coil has been installed to induce the CT to tear loose from the gun sooner. The use of this coil is observed to speed up the magnetic field reconnection process by about a factor of 2.

In the CTX experiment at Los Alamos National Laboratory we have been studying compact toroids (CTs) of the Spheromak type generated with a magnetized coaxial plasma gun. The CTX facility, which is designed to be used for the trapping and study of compact toroids, consists of a large vacuum vessel (4.5-m long and 1.5-m diameter) with DC trapping fields of up to 10 kG. To produce the CT a solenoidal coil is placed inside the inner electrode of a coaxial plasma gun. This coil produces axial magnetic field inside the inner electrode which diverges at the gun muzzle becoming radial. When the gun is

fired, the highly conductive emerging plasma stretches the radial field lines in the axial direction away from the gun. These elongated field lines reconnect behind the plasma forming the closed poloidal field of the CT, with the magnetic field generated by the gun current becoming the embedded toroidal field. CTs generated in this manner have been trapped in prolate and oblate cylindrically symmetric metallic flux conservers. The plasma and magnetic field properties are studied using magnetic probes, pressure probes, interferometry, Thomson scattering, and spectroscopy.

The length of the coaxial gun used in these experiments is 1.2 m, and its inner and outer electrodes have radii of 0.10 m and 0.15 m respectively. The total D_2 gas puffed into the gun with a fast valve ranged from 0.75 to 3.75 cm³ atm. About 150 μ s after the gas valve is pulsed, the gun is energized with a 74 μ F capacitor bank charged to 45 kV. About 2.5 μ s after the initiation of the discharge the gun current peaks with a value of about 1 MA.

In earlier experiments¹ CTs generated in the manner described above were injected into a simple, stainless steel, right-circular, cylindrical flux conserver. The CTs were stopped within the flux conserver by adjusting the initial "poloidal" field strength of the coaxial source. In some cases the CT stopped with its axis parallel to the common axis of the source and flux conserver, and then it rotated (tilted) until its axis was orthogonal to the axis of the flux conserver. In most cases the stopped CT when first observed was already partially tilted. The tilted CT appeared grossly MHD stable, and the magnetic fields of the CT decayed with about a 100 μ s time constant. Interferometric measurements showed an initial density of about 10^{14} cm⁻³ and a density lifetime similar to that of the magnetic field. Details of this work are reported elsewhere.¹ We have also produced CTs within the same flux conserver in the presence of an additional magnetic guide field antiparallel to the magnetic moment of the CT. In this case the CT was observed to rotate

180°, and the characteristic decay time of the magnetic field configuration was only 10-15 μ s (i.e., much shorter than comparable conditions without the guide field). We speculate that the rapid destruction in the guide field case is due to reconnection of magnetic field lines in the high shear regions which occur after the toroid rotates, opening previously closed field lines.

In an attempt to stabilize the tilting of compact toroids produced by the magnetized gun, we have generated compact toroids in other flux conservers having oblate regions incorporated into their geometry.² Cross sections of such flux conservers are shown in Fig. 1. The plasma from the magnetized gun is injected from the left through the 0.34-m diameter entrance cylinder into the confining region. With the geometry of Fig. 1b the tilting no longer occurs and the configuration is stable throughout its lifetime.

The effects on the tilting instability of the geometry of the entrance cylinder and its spacing from the gun muzzle have been investigated. The experiments were done for the geometries drawn in Fig. 1b and Fig. 1d. Increasing the diameter of the entrance cylinder from 0.34 m to 0.46 m caused tilting of the CT, for conditions where it had been stable at the smaller diameter. Keeping the diameter of the entrance region at 0.34 m but increasing the length from 0.34 m to 0.50 m was also found to cause the CT to tilt. The effect of the gap spacing between the gun and the entrance region of the flux conserver was also investigated. Gap spacings of 0 m, 0.05 m, and 0.08 m were tried. It was found that the system becomes progressively more unstable to tilting as the gap spacing is increased.

With the elimination of the complication of tilting, three distinct time scales emerge. The first ($\sim 1 \mu$ s) is the time required to fill the flux conserver with magnetic field and plasma. The second ($\sim 12 \mu$ s) is the time for the decay of the fields in the entrance cylinder. Figure 2a shows this decay. We interpret this decay as being due to field line reconnection which is

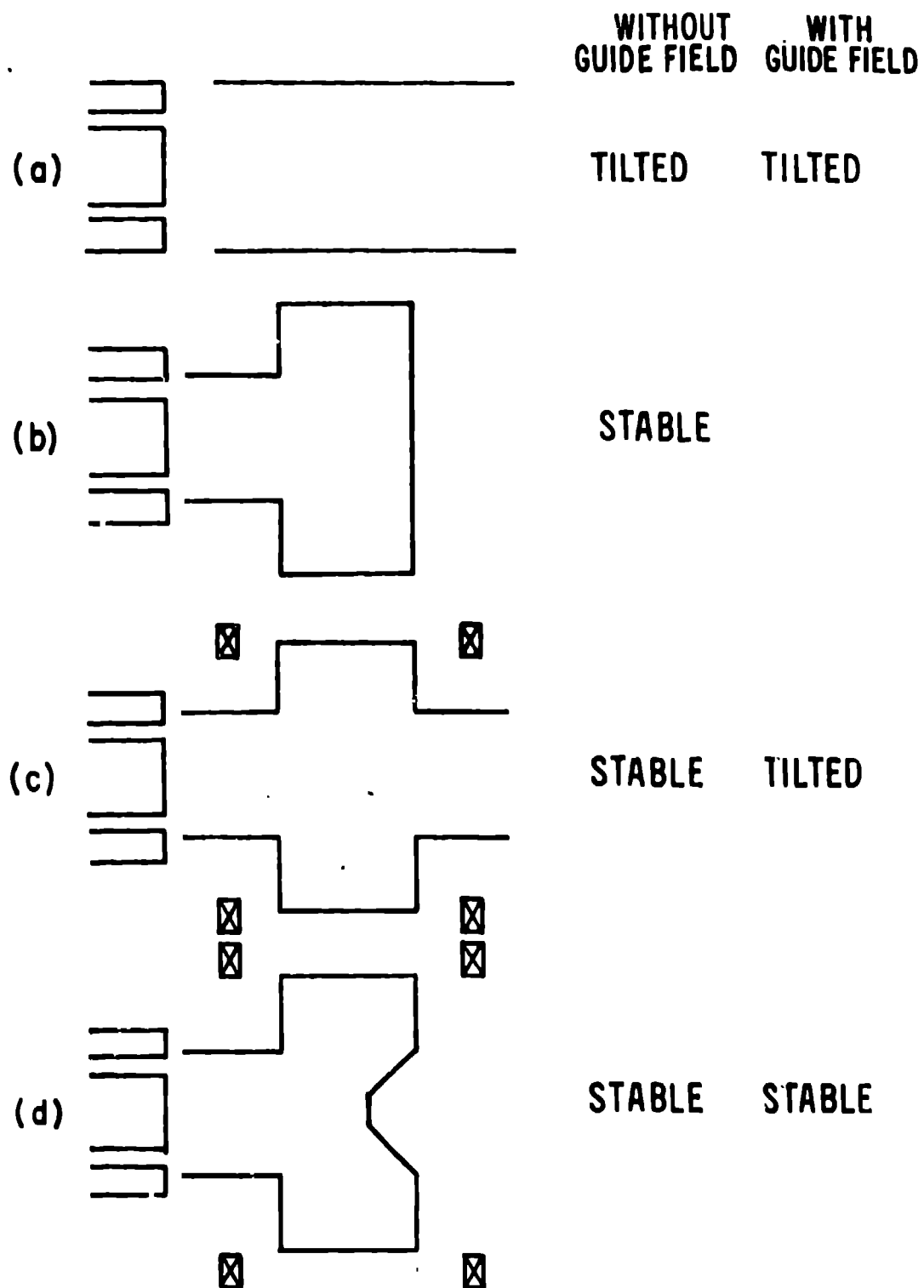


Fig. 1. Various flux conserver geometries used in the investigation of the tilting mode.

If the CT does not tilt one expects no transverse components of \vec{B} on axis. For the case in Fig. 2 the peak transverse components are measured to be less than 15% of the peak B_z and are not shown. The measurement of all components of the magnetic fields on the axis of the flux conserver is a powerful means of determining the extent of tilting. Considerable time was spent searching for a field and flux conserver configuration which gives a stable CT with guide

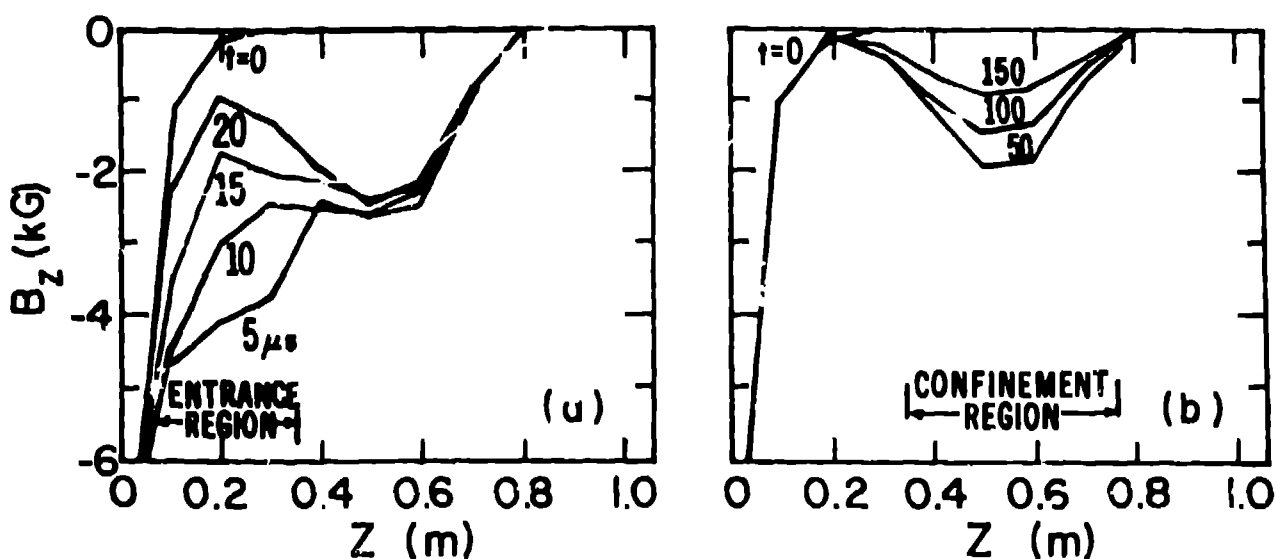


Fig. 2. Plots of the axial component of the magnetic field on axis at various times. Figure 2a shows plots at various times during the decay of the field in the entrance cylinder. The time elapsed between plots is 5 μ s. Figure 2b shows plots at various times during the decay of the compact toroid and the time between plots here is 50 μ s. The gun discharge is initiated at $t=0$ and the plot labeled $t=0$ shows the value of the axial component of the magnetic field in this region due to the coils which supply the initial axial flux for the plasma gun.

field. Figure 1 shows a summary of the geometries tried with comments as to the stability of the CTs created in these geometries.

Some properties of the CT plasma have been measured for the geometry shown in Fig. 1b without external guide field. The density as a function of time as measured by a 3.39 μm wavelength HeNe interferometer is shown in Fig. 3. Observe that the time behavior of the magnetic field and density are similar. Spectroscopic data are taken with a 5-channel polychromator, a monochromator, and a spectrograph. The polychromator has five channels spaced 1 \AA apart. Photomultipliers are used for time resolution. The monochromator has a 2- \AA spectral width. Using both the polychromator and the monochromator two regions of wavelength can be monitored on each shot. The spectrometer which covers a region of approximately 100 \AA , is time integrated, and is used to identify spectral lines. Nickel and iron impurities have been identified. Thomson scattering is used to measure the electron temperature at a position 5 cm from the midplane of the confinement region and at a radius equal to two-thirds of that of the confinement region. There is a large shot-to-shot variation of the temperature and density at this position, especially early in time. On shots where the density is high enough to get good scattering signal, the plasma appears to be fairly cool ($T_e \sim 10$ eV) at later times ($t > 50$ μs). Early in time ($t \sim 5$ μs), long before reconnection is completed, temperatures as high as 60 eV have been measured. Quartz pressure probe data show a rapid pressure drop early in time and are consistent with the Thomson scattering temperature measurements. The time histories of impurity lines such as OIV are also consistent with the Thomson scattering measurements.

A "snipper coil" has been designed and installed on the entrance region of the flux conserver geometry of Fig. 1d. The purpose of this coil is to speed up the magnetic field reconnection in the entrance region by the application of a fast rising external field. One reason for desiring faster magnetic field

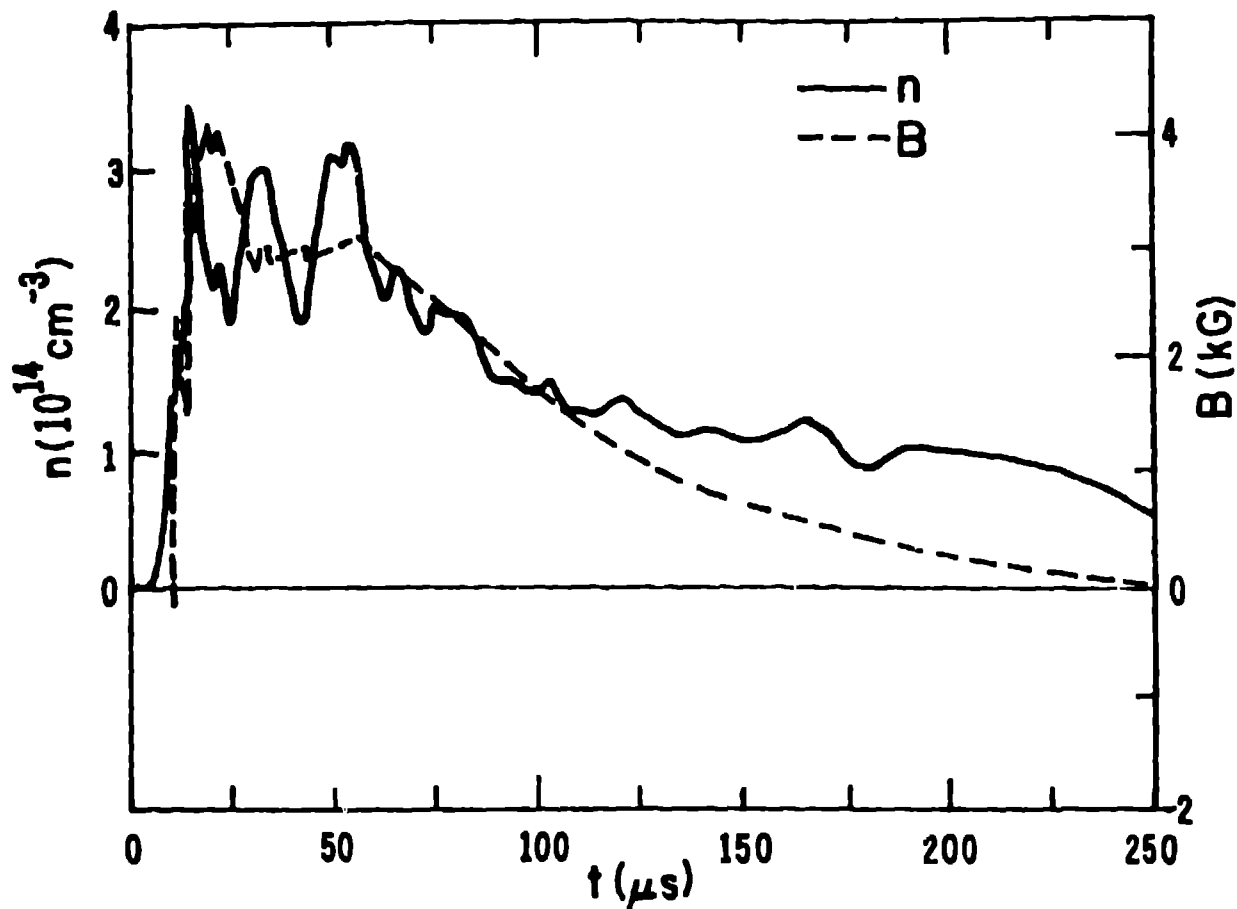


Fig. 3. Density and magnetic field as a function of time in the midplane of the confinement region of the flux conserver. The density is the line average on a diameter and the magnetic field is B_z on axis. The two measurements are from different shots with similar initial conditions.

reconnection is that electron thermal conduction along open field lines may be a major cause of the observed rapid temperature drop at early times. To allow for this additional pulsed field, the metallic conductor forming the entrance region has been replaced by a 0.40-m diameter insulator. This insulator has a series of metallic strips inside its inner surface to allow axial currents to flow at the wall. These currents will tend to contain the azimuthal flux of

the passing plasma (i.e., the flux which becomes the toroidal flux when the CT is formed), while allowing the sniper coil flux to enter. The sniper coil is energized by a 24-kJ, 60-kV capacitor bank, and its current has a quarter period of about 3.5 μ s. The sniper coil current is crowbarred near its peak.

Initial operation with the sniper coil geometry, but without the coil being energized, established that CTs were still formed in the trapping region despite the modified entrance region. The plasma emerging from the coaxial source forced a large fraction ($\sim 50\%$) of the poloidal flux out through the insulator in the entrance region, and the time for the reconnection process to become complete increased by about 50%. The lifetimes of the CTs as determined by the magnetic field structure were in this unsnipped case about the same as for the earlier case with the conducting-walled entrance region.

Results when the sniper coil is energized are very preliminary. The timing of the sniper coil with respect to the beginning of plasma flow out of the coaxial source is found to be very important. When the sniper coil is energized with its present bank the reconnection time has been measured by the reversal of B_z on axis in the entrance region. It is found to be three times faster than if the sniper coil is not energized, and two times faster than observed in the original case with a conducting-walled entrance region. So far no conclusions are possible concerning whether the present sniper coil or CTX is beneficial because there is insufficient data. Making straightforward comparisons of cases when the sniper coil was energized with cases when it was not is rather difficult because of shot-to-shot variations. Encouraging results have been obtained on isolated shots. For example lifetimes (as defined by the existence of closed poloidal flux in the CT) of nearly 300 μ s have been observed, and temperatures of 30 eV at 50 μ s and 20 eV at 100 μ s have been measured. However, these shots are not repeatable, and it is unclear what effect (if any) the sniper coil had in producing them.

REFERENCES

1. T. R. Jarboe, I. Henins, H. W. Hoida, R. K. Linford, J. Marshall, D. A. Platts, and A. R. Sherwood, "The Motion of a Compact Toroid Inside a Cylindrical Flux Conserver," Phys. Rev. Lett. 45, 1264 (1980).
2. T. R. Jarboe, I. Henins, H. W. Hoida, R. K. Linford, J. Marshall, D. A. Platts, A. R. Sherwood, "Production of Field-Reversed Configurations With a Magnetized Coaxial Plasma Gun," International Symposium of Physics in Open-Ended Fusion Systems, Tsukuba, Japan, April 15-18, 1980.